

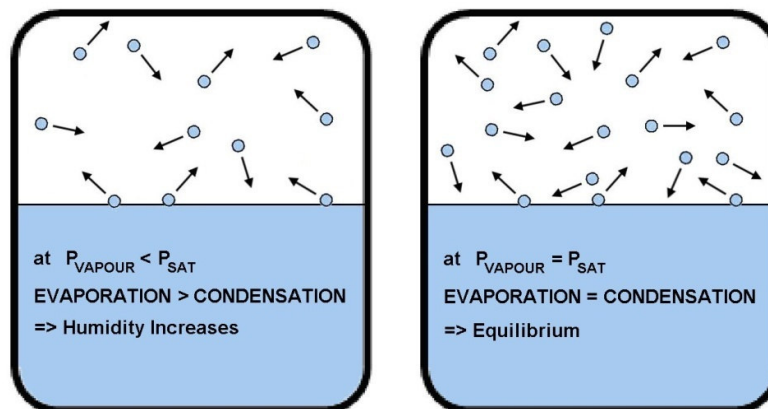
## UNDERSTANDING HUMIDITY

This application note discusses the following:

- Saturated Vapour Pressure
  - Evaporation
  - The variation of saturated vapour pressure and temperature
  - Saturated vapour pressure and boiling point
  - The effect of saturated salt solutions
- Humidity
  - Absolute humidity, Specific humidity, Mixing ratio, Partial vapour pressure, Dew point
- Relative Humidity
  - Why relative humidity over absolute humidity
  - Relative humidity control
- Determining the Dew Point
  - Human reaction to dew point temperature

### 1 SATURATED VAPOUR PRESSURE?

#### 1.1 Evaporation



**Figure 1 - Vapor evaporates from the surface of water increases the vapor pressure. At the Saturated Vapor Pressure the amount of evaporation and condensation reaches equilibrium.**

The average energy of the particles in a liquid increases with temperature. Within that average, some particles have energies higher than the average, while others have energies lower than the average. Some of the more energetic particles on the surface of the liquid can be moving fast enough to escape from the attractive forces holding the liquid together, hence they evaporate.

Evaporation only takes place on the surface of the liquid. This is quite different from boiling, which only happens when there is enough energy to disrupt the attractive forces throughout the liquid. That's why, if

you look at boiling water, you see bubbles of gas being formed all the way through the liquid. However, if you look at water which is just evaporating in the sun, you don't see any bubbles. Water molecules are simply breaking away from the surface layer.

Eventually, all the liquid will evaporate in this way. The energy which is lost as the particles evaporate is replaced from the surroundings. As the molecules in the water jostle with each other, some of the remaining molecules will gain enough energy to escape from the surface.

Now imagine what happens if the liquid is in a closed container. Common sense tells you that a liquid in a sealed bottle doesn't seem to evaporate - or at least, it doesn't disappear over time. But there is constant evaporation from the surface. Particles continue to break away from the surface of the liquid, but this time they are trapped in the space above the liquid. As the gaseous particles bounce around, some of them will lose energy and return to the liquid state, condensation. Equilibrium is reached where the number of particles leaving the surface is exactly balanced by the number rejoining it. In this equilibrium, there will be a fixed number of the gaseous particles in the space above the liquid. At this point the vapour is said to be saturated, and the pressure of that vapour is called the saturated vapour pressure.

## 1.2 The Variation of Saturated Vapour Pressure with Temperature

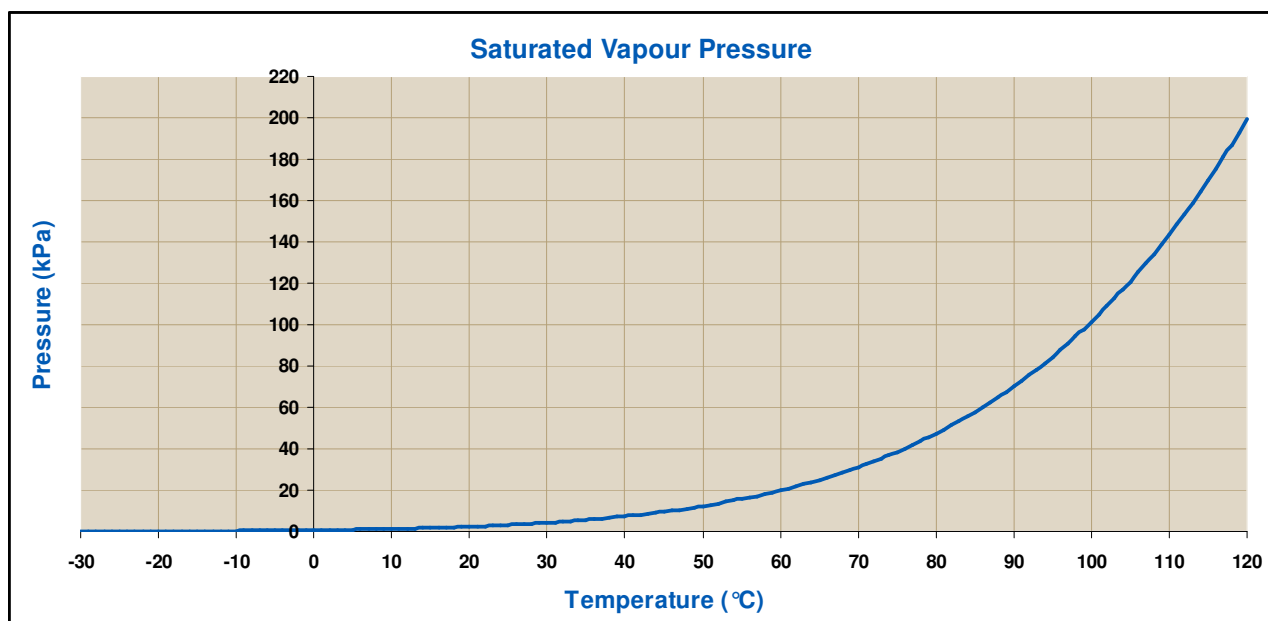
As the temperature increases, the average kinetic energy of the particles increases and more molecules gain enough energy to evaporate. Equilibrium will be restored, but, this time at a higher vapour pressure – causing an increase in the saturated vapour pressure.

The Antoine Equation can be used (other more complex formulae are available) to calculate the saturated vapour pressure of a liquid for a given temperature. The Antoine equation for water is:

$$\log_{10} P_{\text{SAT}} = 7.196 - \frac{1730.63}{233.43 + T}$$

where,  $P_{\text{SAT}}$  is the saturated vapour pressure (kPa) and  $T$  is the temperature ( $^{\circ}\text{C}$ ).

A graph of this function in the temperature range of  $-30^{\circ}\text{C}$  to  $+120^{\circ}\text{C}$  is shown in figure 2. As can be seen from the graph, the saturated vapour pressure varies greatly with temperature. Atmospheric pressure is 101.325 kPa, which as you can see from the graph corresponds to a temperature of  $100^{\circ}\text{C}$  – which we know is the boiling point of water.



**Figure 2 – Saturated Vapour Pressure of Water in the range  $-30^{\circ}\text{C}$  to  $120^{\circ}\text{C}$**

The saturation point can also be specified as the saturated vapour density as specified in table 1 below.

| Temp | Saturated Pressure (kPa) | Saturated Vapour Density (g/m <sup>3</sup> ) |
|------|--------------------------|--|
| -10  | 0.287                    | 2.36   |
| 0    | 0.61                     | 4.85   |
| 10   | 1.23                     | 9.4  |
| 20   | 2.34                     | 17.3   |
| 30   | 4.24                     | 30.4   |
| 40   | 7.37                     | 51.1   |
| 60   | 19.9                     | 130.5  |
| 80   | 47.3                     | 293.8  |
| 100  | 101.3                    | 598  |
| 200  | 1554.4                   | 7840   |

**Table 1 – Saturated vapour pressure and saturated vapour density of water from -10 °C to +200 °C**

### 1.3 Saturated vapour pressure and boiling point

A liquid boils when its saturated vapour pressure is equal to the external pressure on the liquid. When that happens, bubbles of vapour form throughout the liquid. If the external pressure is higher than the saturated vapour pressure, these bubbles are prevented from forming, and you just get evaporation at the surface of the liquid.

At different pressures, water will boil at different temperatures. For example, at the top of Mount Everest the pressure is so low that water will boil at about 70 °C. At sea level pressure variations of ±30mbar are normal and change the boiling point of water by more than ±1 °C.

### 1.4 Saturated salt solutions

A saturated salt solution can be used to alter (usually lower) the saturated vapour pressure within a closed environment. Altering the saturated vapour pressure will alter the maximum relative humidity and in equilibrium can be used to maintain a constant relative humidity, which is repeatable. By providing excess solute (salt), the solution will remain saturated even in the presence of modest moisture sources and sinks. A list of common salts and the resultant relative humidity in a confined space is presented in table 2.

| Temp (°C) | Lithium Chloride | Magnesium Chloride | Potassium Carbonate | Sodium Chloride |
|-----------|------------------|--------------------|---------------------|-----------------|
| 0         | 11.23            | 33.66              | 43.13               | 75.51           |
| 10        | 11.29            | 33.47              | 43.14               | 75.67           |
| 20        | 11.31            | 33.07              | 43.16               | 75.47           |
| 30        | 11.28            | 32.44              | 43.17               | 75.09           |
| 40        | 11.21            | 31.60              | -                   | 74.68           |

**Table 2 – Relative Humidity in the presence of various saturated salt solutions**

Saturated salt solutions affect the humidity of the air above it, by reducing the amount of water molecules available to be evaporated. In the case of a saturated solution of sodium chloride, each sodium and chlorine ion actually is surrounded by a shell of water molecules held by strong ionic attraction between the ion and the polar water molecule. This attraction (hydration energy) is nearly as strong as that which the sodium and chlorine ions have for one another (this is why salt so readily dissolves in water). Therefore, the water molecules in this hydration shell are not as free to evaporate as those in a solution of pure water. The net effect is that there are fewer water molecules available for evaporation and so the vapour pressure is reduced, within that closed environment

## 2 HUMIDITY

Humidity is a measure of the amount of water vapour present in a gas – typically air. There are several ways to quantify humidity.

### 2.1 Absolute Humidity

Absolute Humidity expresses the water vapour content of the air using the mass of water vapour contained in a given volume of air. It is generally measured in grams of water per cubic meter of air (g/kg).

A problem with using absolute humidity is that a quantity of air changes volume, as the ambient temperature and pressure change. This means that the absolute humidity changes will change with temperature and pressure, even though the mass of water vapour has not changed.

### 2.2 Specific Humidity

Specific Humidity measures the water vapour content of the air using the mass of the water vapour for a given mass of air. It is usually measured in grams of water vapour per kilogram of (wet) air. The kilogram of air measured includes the water vapour present. Unlike absolute humidity, specific humidity does not vary with temperature or pressure.

### 2.3 Mixing Ratio

Mixing Ratio measures the water vapour content using a measure of mass, but it measures the mass of water vapour for a given mass of dry air. It is generally measured in kilograms of water vapour per kilogram of dry air.

Since water vapour comprises only a few percent of the mass of air, the values for specific humidity and mixing ratio are very close. Mixing ratio is not affected by changes in pressure and temperature, except when the temperature is less than the dew point.

The Mixing Ratio is generally preferred by meteorologists.

## 2.4 Vapour Pressure

Vapour pressure measures the water vapour content of the air using the partial pressure of the water vapour in the air. The contribution by water vapour is rather small, since water vapour only makes up a few percent of the total mass of air.

## 2.5 Dew Point

The dew point is the temperature to which air must be cooled (at constant pressure) for all the water vapour to condense into water. The condensed water is called dew. The dew point is associated with relative humidity (which is discussed in more detail in section 3). A high relative humidity indicates that the dew point temperature is closer to the current air temperature. Relative humidity of 100% indicates that the dew point temperature is equal to the current temperature (and the air is saturated with water).

The dew point temperature is an important statistic for general aviation pilots, as it is used to calculate the likelihood of carburettor icing and fog, and estimate the height of the cloud base. The dew point is often calculated from a known temperature and relative humidity. See section 4 for a detailed discussion on determining the dew point.

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## 3 RELATIVE HUMIDITY

Relative humidity is a ratio that compares the actual amount of water vapour present in the air with the amount of water vapour that would be present in the air at saturation. Relative humidity is expressed as a percentage:

$$RH(\%) = \frac{\text{Vapour Pressure}}{\text{Saturated Vapour Pressure}} \times 100\% .$$

The saturated vapour pressure increases greatly with temperature, as shown in figure 2. This means that a temperature increase (or decrease) in a system with no change to the water vapour in the system, causes an increase (or decrease) in the saturated vapour pressure causing the Relative Humidity to decrease (or increase).

### 3.1 Why Relative Humidity over Absolute Humidity

Humans are sensitive to humid air, because the human body uses evaporative cooling as the primary mechanism to regulate temperature. When the relative humidity is high, the rate of evaporation of perspiration from the skin decreases because the amount of water vapour in the air is already close to saturation. Because humans perceive the rate of heat transfer from the body, rather than temperature itself, we feel warmer when the relative humidity is high. Hence, relative humidity can be used to indicate how hot the weather feels.

For these reasons above relative humidity is not only a more useful measurement (in general) than absolute humidity, it is also more intuitive and easier to measure.

### 3.2 Relative Humidity Control

Traditionally an environment was controlled based on a temperature measurement; however, in recent years the relative humidity measurement is becoming just as important. Humidity control is especially important in living, storage, and manufacturing sites.

Control of temperature and relative humidity is also critical in the preservation of many materials, because unacceptable levels of temperature and/or relative humidity contribute significantly to the breakdown of materials. Heat accelerates deterioration, whereas high relative humidity provides the moisture necessary, to promote harmful chemical reactions in materials and, in combination with high temperature, encourages mould growth and insect activity. Extremely low relative humidity, which can

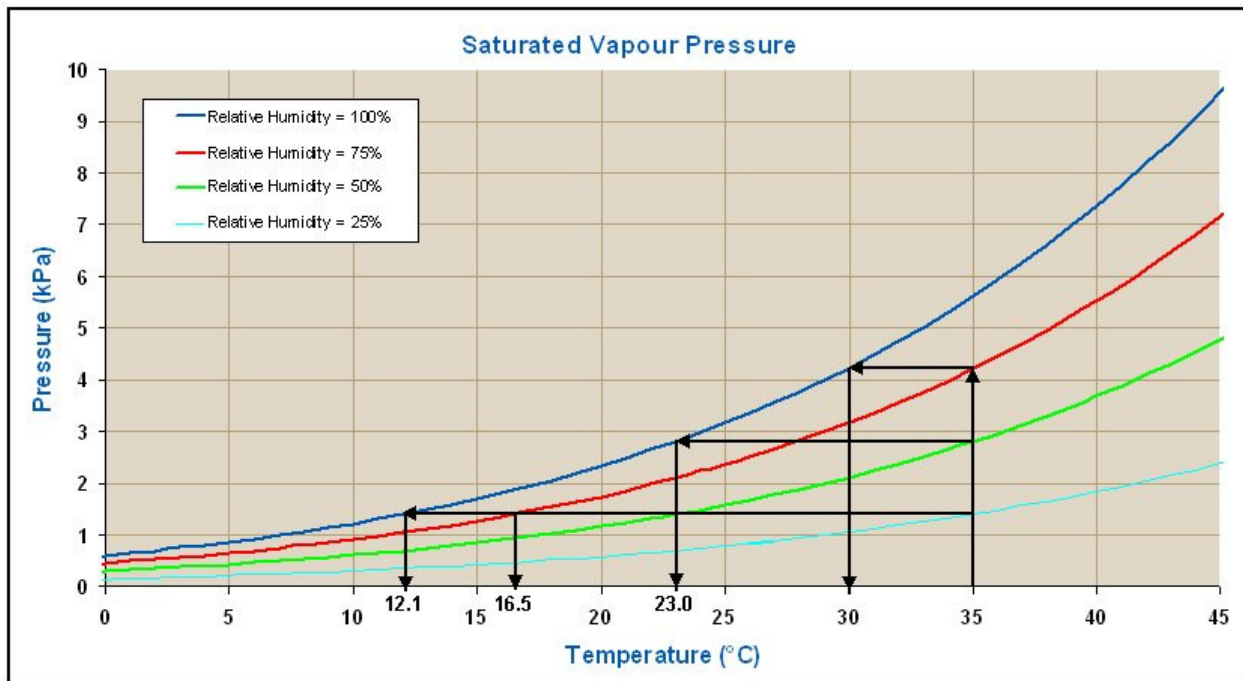
occur in winter in centrally heated buildings, may lead to desiccation and embrittlement of some materials. Large fluctuations in temperature and relative humidity are damaging due to expansion and contraction, accelerating deterioration.

Installation of adequate climate controls and operation of them to maintain preservation standards will retard the deterioration of materials considerably, while maintaining a comfortable environment. The ideal temperature and relative humidity will vary depending on the material and application but a steady temperature of 16°C to 21°C and a relative humidity between 30% and 60% suffices for many applications – however it is generally agreed that maintaining stable conditions is crucial.

## 4 DETERMINING THE DEW POINT

A chart of the vapour pressure of water at various relative humidity is shown in figure 3. This graph can be used to calculate the dew point of air for any known temperature and relative humidity. This can be read from the graph by drawing a vertical line at the temperature until it hits the vapour pressure curve for the particular relative humidity. From this point, a horizontal line is then drawn until it hits the 100% relative humidity curve (saturated vapour pressure). The dew point is the temperature that this occurs at. For example:

- Air at 35°C and 75% relative humidity has a dew point of 30°C
- Air at 35°C and 50% relative humidity has a dew point of 23°C
- Air at 35°C and 25% relative humidity has a dew point of 12.1°C
- Air at 16.5°C and 75% humidity also has a dew point of 12.1°C.



**Figure 3 - Graphical reading of the dew point**

Instead of reading the dew point from the graph as shown above, the dew point can also be calculated from a known temperature and relative humidity by using the following equation:

$$T_d = 243.12 \times \frac{\log\left(\frac{RH}{100\%}\right) + \frac{17.62 \times T}{243.12 + T}}{17.62 - \left(\log\left(\frac{RH}{100\%}\right) + \frac{17.62 \times T}{243.12 + T}\right)}$$

where,  $T_d$  is the dew point temperature ( $^{\circ}\text{C}$ ), RH is the relative humidity (%) and T is the temperature ( $^{\circ}\text{C}$ ).

#### 4.1 Human reaction to high dew points

Humans tend to react with discomfort to a high dew point ( $>16^{\circ}\text{C}$ ). The body perspires and produces sweat to cool down. High relative humidity and consequently a high dew point prevent the evaporation of sweat and reduce evaporative cooling. As a result, the body may overheat, resulting in discomfort.

Lower dew points ( $<10^{\circ}\text{C}$ ) correlate with lower ambient temperatures, and the body requires less cooling. A lower dew point can be achieved with a high temperature, but only at extremely low relative humidity allowing for effective cooling.

Those accustomed to continental climates often begin to feel uncomfortable when the dew point reaches between  $15^{\circ}\text{C}$  and  $20^{\circ}\text{C}$ . Most inhabitants of these areas will consider dew points above  $21^{\circ}\text{C}$  to be oppressive.

| Dew Point ( $^{\circ}\text{C}$ ) | Equivalent RH at $30^{\circ}\text{C}$ | Human Perception   |
|----------------------------------|---------------------------------------|--|
| $>24$                            | 70%                                   | Extremely uncomfortable, oppressive                      |
| $21 \rightarrow 24$              | 58% $\rightarrow$ 70%                 | Very humid, quite uncomfortable                          |
| $18 \rightarrow 21$              | 49% $\rightarrow$ 58%                 | Somewhat uncomfortable for most people at upper edge     |
| $16 \rightarrow 18$              | 43% $\rightarrow$ 49%                 | OK for most, but all perceive the humidity at upper edge |
| $13 \rightarrow 16$              | 35% $\rightarrow$ 43%                 | Comfortable  |
| $10 \rightarrow 12$              | 29% $\rightarrow$ 35%                 | Very comfortable   |
| $<10$                            | $<29\%$                               | A bit dry for some                                       |

**Table 3 – Human reaction to dew point temperatures**